PB86-166006

United States Practice in Sludge Treatment and Disposal

(U.S.) Environmental Protection Agency
Cincinnati, OH

Feb 86

U.S. Department of Commerce
National Technical Information Service
NTIS

PB86-166006

EPA/600/D-86/043
February 1986

UNITED STATES PRACTICE IN SLUDGE TREATMENT AND DISPOSAL

by

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SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA/600/D-86/043	2.	3. RECIPIENT'S ACCESSION NO. PB86 166006/AS
4. TITLE AND SUBTITLE United States Practice in Sludge Treatment and Disposal		5. REPORT DATE February 1986 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) J. B. Farrell		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Wastewater Research Division Water Engineering Research Laboratory 26 West St. Clair Street Cincinnati, OH 45268		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Water Engineering Research Laboratory, Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, OH 45268		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES Author: Dr. J. B. Farrell (513) 569-7645 FTS 8-684-7645		

16. ABSTRACT

Sludge treatment and disposal problems and costs grow with increased concern about the quality of wastewater treatment. As standards for effluent quality in the United States have become stricter, the problems of sludge treatment and disposal have grown disproportionately. There is much more sludge being produced. Much of the increase has been in biological and chemical sludges which are hard to treat. Today the costs of sludge treatment and disposal at a modern metropolitan sewage treatment plant represent almost half the cost of wastewater treatment.

Sludge problems, although of serious concern everywhere, are different for different locations. The approach to sludge handling and the solution to problems depends on geography, climate, population, proportion and nature of industrial wastes in the wastewater, and local details (e.g., proximity of hills, rivers, residences, farmland, landfills, strip-mined land). The net result has been innumerable different approaches to sludge handling, and a great variety of processes and equipment. The following presentation scans U. S. practice and identifies the predominant and more successful approaches to sludge treatment and disposal that have developed over the years.

17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) Unclassified 20. SECURITY CLASS (This page) Unclassified	21. NO. OF PAGES 28 22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

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Sludge treatment and disposal problems and costs have grown with increased concern about the quality of wastewater treatment. As standards for effluent quality in the United States have become stricter, the problems of sludge treatment and disposal have grown disproportionately. There is much more sludge being produced. Much of the increase has been in biological and chemical sludges which are hard to treat. Today the costs of sludge treatment and disposal at a modern metropolitan sewage treatment plant represent almost half the cost of wastewater treatment.

Sludge problems, although of serious concern everywhere, are different for different locations. The approach to sludge handling and the solution to problems depends on geography, climate, population, proportion and nature of industrial wastes in the wastewater, and local details (e.g., proximity of hills, rivers, residences, farmland, landfills, strip-mined land). The net result has been many different approaches to sludge handling, and great variety in processes and equipment. The following presentation scans U. S. practice and identifies the predominant and more successful approaches to sludge treatment and disposal that have developed over the years.

Nature and Quantity of Residual Streams

A sewage treatment plant usually produces three small residue streams in addition to the larger volume sludge stream. Typically, wastewater is subjected to coarse screening and grit removal before treatment, producing screenings and grit. A small amount of total oil and grease in the sewage floats to the top of the primary and secondary clarifiers. This "scum" is skimmed off, producing the "skimmings" stream.

Screenings. Typically wastewater passes through coarse screens (greater than 6 mm, more usually 20+mm). Quantities removed are small and variable depending on screen size, presence of combined sewers, season of the year, and plant location. Data in a tabulation of results (1) were listed in order of increasing magnitude and showed the following volumes per volume of wastewater processed:

percentile	mL screenings/m^3 wastewater
25%	3
50%	8
75%	11

Disposal of this material is frequently troublesome because of its unpleasant odor and potential disease hazard. Ordinarily it is disposed of by burial in a landfill.

Grit. Typically grit is removed after the screening step but before primary clarification in an aerated grit chamber. It contains gravel, sand, broken glass, and pieces of metal, and is contaminated with fecal wastes and other solid components in sewage. Data from a tabulation of typical quantities (2), arranged in order of increasing magnitude, show the following:

percentile	mL grit/m^3 wastewater
25%	12
50%	20
75%	50

Grit is sometimes incinerated, but more usually it is disposed by burial in a landfill.

Skimmings. Scum is typically collected from primary and secondary clarifiers and combined in a stream called skimmings. It is not related to the total content of grease and oil in sludge which is much greater in quantity. Data from a tabulation of results (3), arranged in order of increasing magnitude, show the following:

percentile	mL skimmings/m^3 wastewater
25%	6
50%	22
75%	90

This stream is not all organic oils but contains considerable amounts of water and solid plastic articles. Ordinarily skimmings are burned or buried. Some plants have sold skimmings to refineries for soap manufacture or other uses. This practice is less common today, possible because organic toxicants may concentrate in this stream. Some plants receiving wastewater from metal forming industries, which frequently have more-than-usual amounts of mineral oil in the wastewater, have attempted to develop a usable fuel from the skimmings, but there has been no significant acceptance of this concept.

Sludge. Typically in the United States, the total mass of sludge solids, before any subsequent treatment, is 90 g sludge solids per capita-day based on a population equivalent production of 378 liters of wastewater per day. About half of this total mass is primary sludge, and the remainder is sludge from secondary treatment processes. This is the approximate amount of sludge from a plant with an influent BOD_5 of 250 mg/L, suspended solids of 250 mg/L, and producing an effluent of 10 mg/L BOD_5 and 10 mg/L suspended solids.

If this sludge were concentrated to about 4 percent solids, the volume of sludge would amount to about 6000 mL/m^3 of wastewater, compared to about 50 mL/m^3 for the combined volume of the screenings, grit, and skimmings streams. The composition of the major constituents of primary sludge is presented in Table 1. Table 2 shows a typical composition waste activated sludge.

The concentration of trace metals and organic compounds can be a source of substantial concern for certain disposal options. Distribution of metals in digested sludges from wastewater treatment plants with a substantial industrial component in their wastewater is presented in Table 3. Organic compounds in sludge are of increasing concern. Data collected in a recent EPA study are presented in Table 4. These data are for mixtures of primary and secondary sludges before digestion.

In the United States, it is common for wastewater treatment plants to have a good knowledge of trace metal content of their sludges. Such information is important for several disposal options, and analytical equipment is relatively inexpensive and easy to operate. For organic compounds, generally information is sparse. Analytical equipment is very expensive and analytical methods are complex and frequently unreliable. Potential problems from organic compounds in sludge nevertheless can not be neglected. A procedure which suffices in most cases is to know very well the nature of the industries discharging to the wastewater treatment plant. In the several cases in the United States where toxic metals or organic compounds were found in health-threatening concentrations in sludge, this potential could have been discovered by an examination of the raw materials and products list of the industries discharging into the wastewater. When there is good reason to suspect contamination by an organic toxicant, the sludge should be analyzed for the chemical.

Thickening

Thickening of sludge streams is ordinarily highly cost-effective. Volume of sludge is reduced, so all downstream equipment, such as digesters, can be reduced in size. Despite this advantage, thickening is frequently omitted in small plants serving populations less than 10,000, particularly if they are in rural surroundings. In these small plants, waste secondary sludge is returned to the primary clarifier where it is collected with the primary sludge. The mixed sludge is aerobically or anaerobically digested, and dried on sand beds. The overall capital cost of the plant is somewhat higher than it would be if sludge were thickened, but the plant requires less operating time and a smaller skilled operating staff. At larger plants, sludges are thickened by gravity, dissolved air flotation or centrifugation.

Gravity Thickening. Gravity thickening is the most common thickening practice in the United States. A typical circular gravity thickener is shown in Figure 1. Gravity thickeners are cheap and rugged. They are used for primary and mixed sludges, although performance is frequently poor for mixed sludges--supernatants are high in solids and sludge is not thickened to the desired solids concentrations. Odor is frequently a problem, particularly in hot weather--there is a strong trend toward covering thickeners in the United States. Polymer conditioning agents are not usually used with gravity thickeners.

Dissolved Air Flotation. Dissolved air flotation (DAF) is frequently used to thicken waste activated sludge streams, and it works successfully for mixed sludges. A schematic diagram of a DAF unit is shown in Figure 2. Ordinarily a waste activated sludge can be thickened to over 4 percent solids with no difficulty. Polymer conditioning agents are frequently used. They increase production rate, but more importantly they reduce solids losses in the underflow. Odor is not usually a problem because the residence time in the unit is short and the sludge is saturated with air.

Centrifugal Thickening. Disk-nozzle (Figure 3) and solid-bowl decanter centrifuges (Figure 4) have been used as thickeners for waste activated sludges. Disk-nozzle centrifuges have been plagued with erosion and plugging problems. Their use is declining for sludges from municipal wastewater treatment plants. On the other hand, the use of solid-bowl decanter centrifuges for thickening waste activated sludges is increasing. Superior designs operating at lower speeds and/or using hard-faced wearing parts can operate consistently for long periods. Polymeric conditioning agents are frequently not needed. If they are, it is at low concentrations (about 5 mg/kg sludge solids). A continuing trend to use solid-bowl centrifuges for thickening waste activated sludges is expected.

Conditioning for Dewatering

Most mixed sludges are virtually unfilterable by mechanical dewatering devices unless the sludge is conditioned in some way before dewatering. Dewatering of sludge on sand beds is an exception, although conditioning agents are sometimes used to increase the drying rate. Conditioning agents or methods include addition of inorganic chemicals (lime and/or ferric chloride), addition of polymers (generally organic polyelectrolyte), and heat treatment or low-pressure wet oxidation.

Inorganic Chemicals. The use of chemicals such as lime and/or ferric chloride as conditioning agents has been steadily declining in the United States ever since organic polymers were introduced about 20 years ago. The increased use of belt filters, which require organic polymeric conditioning agents, has contributed to the decline. These chemicals are still used with filter presses and with vacuum filters when polymers do not consistently work well. Ferric chloride alone is frequently the best conditioning agent when a waste activated sludge must be dewatered.

Organic Polymers. The use of organic polymers for conditioning sludge continues to increase in the United States. Operation is simpler and cleaner, and space requirements are reduced when polymers are used. If polymers will successfully condition the sludge, and this is usually the case, the plant will abandon inorganic chemical conditioning in favor of polymer conditioning.

Thermal Conditioning. Low pressure oxidation (see Figure 5) and thermal treatment without oxygen have been used to condition primary, waste activated sludges, and their mixtures in the United States. The effect of these two processes on sludge is essentially the same. Thermally conditioned sludges can be dewatered to solids content in excess of 35 percent when dewatered with vacuum filters. Substantial solubilization of sludge occurs, particularly with waste activated sludges, which substantially increases the recycle load on the treatment plant. A recent EPA survey showed that there were 109 thermal conditioning installations in the United States. Of the 31 heat treatment installations, 9 were operating. Of the 78 low pressure oxidation installations, 75 were operating. The process continues to be used in new construction, although there is a growing awareness that the process requires a high degree of dedication to good operation and maintenance. Many engineers recommend these processes only when it is anticipated that the sludges produced will be very difficult to dewater by other means. The strong supernatants produced require either oversizing the basic treatment process to handle this increased load or separate treatment.

Stabilization

Except when it is to be incinerated, sludge is stabilized by processes such as anaerobic or aerobic digestion, or by chemical treatment. These processes allow sludge to be used on the land or disposed to a landfill.

Anaerobic Digestion. About half of the sludge produced in the United States is anaerobically digested. A simplified diagram of a high rate digestion system is shown in Figure 6. For smaller plants that utilize sand beds, a single, high rate mesophilic (35-37°C) digester is used, and the unthickened processed sludge is discharged to the sand beds when digestion is complete. Larger plants frequently use two digestion stages, with the second stage unheated and serving primarily as a thickener. A second stage digester is an expensive thickener; consequently, thickening after digestion is frequently accomplished in other ways. Some of the largest plants, for example, Chicago and Philadelphia, use a single stage of digestion and thicken their digested sludge in lagoons. Supernatant from the lagoon is generally much lower in suspended solids content than the supernatant from the second stage digester. Other large plants, like Los Angeles County, do not post-thicken sludge but take it directly to centrifugation.

A unique form of digestion, dual digestion, has been installed in a few small plants in the United States. It utilizes a short period of aerobic digestion (1 da) with oxygen, which causes the sludge to reach thermophilic temperatures (over 50°C) followed by 8 days of anaerobic digestion at the temperature at which the system equalizes. Dual digestion provides considerably more pathogen reduction than does conventional mesophilic digestion, but there is some question as to whether it disinfects the sludge.

Anaerobic digesters in the United States typically are cylindrical with low height-to-diameter ratios. Poor mixing is a generally reported problem which results in substantial grit accumulation. There has been a well-publicized demonstration (Treasure Island, Long Beach, California) of an egg-shaped digester which achieves good mixing with little grit accumulation. Unfortunately, costs of this type digester are high. A lower cost way to get more effective mixing with less grit accumulation is much needed.

Aerobic Digestion. Many small plants serving populations less than 10,000 aerobically digest sludge. This process is low in capital cost, easy to operate, but high in energy cost. This cost disadvantage is outweighed by low labor cost and simplicity of operation. However, the process has an important technical disadvantage--the sludge is contacted with air for a long time and generally is cooled to near the wet bulb temperature. In the winter time in many locations, the sludge approaches 0°C and biological activity virtually ceases. Heavy pressure to upgrade this inadequate process is expected in coming years. Conservation of the thermal energy generated in aerobic oxidation of sludge and use of efficient aerators allows temperature of the treated sludge to increase. Energy conservative processes now available in Europe, and others being developed in the United States, offer an attractive alternative to aerobic digestion as conventionally operated.

Lime Treatment. Treatment of sludge with lime, bringing it to a pH of 12, destroys most pathogens (except worm eggs), greatly reduces objectionable odors, and temporarily stops bacterial degradation. Stabilization is adequate provided the sludge is utilized or disposed of rapidly. This process has found substantial use in recent years in the United States. Many small plants which formerly used incinerators switched to lime stabilization during the period when oil prices first skyrocketed a few years ago. The process is an ideal alternative when the principal stabilization process is inoperative or the incinerator breaks down. Probably 100 plants or more use this method of stabilization as their regular means of stabilization, and many others resort to it in emergencies.

Chlorine Treatment. A proprietary process, the Purifax process, is used in some small plants to stabilize sludge. The process is effective but consumption of chlorine is high. Doses correspond to over 2500 mg/L of sludge. The sludge is usually disposed to sand beds. If the acidic drainage from the sludge is returned to the plant influent, its impact is minimal. There is some concern about formation of chlorinated compounds, although formation of specific toxic soluble chlorinated compounds has not been demonstrated.

Dewatering

Sludge must be dewatered before incineration or before transport to landfill, and is dewatered in many cases when sludge is to be applied to the land. The variety of approaches includes drying in lagoons or on sand or paved beds, filtration, and centrifugation.

Drying on Beds. Plants serving small populations frequently use sand beds to dewater anaerobically or aerobically digested sludge. Filtrate drains through the sludge which eventually air dries to a "liftable" solids content. Sometimes the beds are paved. In this case, the sludge settles, leaving a supernatant which is decanted. The remainder of moisture removal is by air drying. A procedure being followed in many locations is to periodically mix the sludge on the bed, using a tractor with a transverse helical conveyor in place of a plow. The helical conveyor thoroughly mixes the sludge and also pushes it aside, allowing the tractor to move rapidly through the bed. The rate of drying is approximately doubled. This procedure has been used to dry out lagoons containing sludge at a depth of 1.5 meters with good results. Vacuum-assisted drying beds have become popular in small cities in the southeastern United States where there are many good drying days but frequent rains. Drying progresses much more rapidly with these beds. Advantage can be taken of dry weather to dewater the bed to the stage where the bed cracks. After that, rain does not greatly increase drying time. Usually polymers are added to sludges to help speed up the filtrate draining step.

Filtration. Filtration has seen great changes in the last 10 or 15 years. Belt filters (see Figure 7) introduced from Europe are the dominant type of filtration device employed. Many vacuum filters are still used but they are seldom specified for new installations. Belt filters use less energy than vacuum filters and require less space. They produce a cleaner filtrate, although this advantage is less than first appears when the solids from belt washing operations are included. Belt filters are suitable for almost all sludges except chemical sludges or sludge to which lime has been added.

Pressure filters (Figures 8a, 8b) with and without diaphragms were introduced into the United States about 15 years ago and usage has grown moderately. Approximately 50 plants in the United States use pressure filters of either of these two types. Pressure filters typically use lime and ferric chloride as conditioning agents, although organic polymeric conditioning agents are seeing some use. In some cases, precoating with ash or a filter aid is needed to protect the filter cloth from blinding. The diaphragm filter press is the most versatile filtering device available. It can produce a dry cake with almost any sludge. The conventional pressure filter occasionally suffers from partially wet cakes, but it is still an extremely versatile filter, able to handle very difficult sludges. High capital cost has slowed the penetration of these filters into the United States market.

Centrifuges. Solid-bowl decanter type centrifuges are the dominant type of centrifuge used in dewatering sludges. Numerous installations of imperforate basket centrifuges (Figure 9) were made a few years ago primarily because they produced good solid recoveries at low polymer demand. Continuous development of improved belt filters and solid-bowl decanter centrifuges (Figure 4) have since then dominated the market. Many large cities utilize solid-bowl decanter centrifuges to dewater their sludges (e.g., Los Angeles County, Chicago, Cleveland, Denver, Seattle, San Francisco, Philadelphia, Atlanta), and are pleased with their choice. As noted earlier, superior designs, better controls (backdrive speed control), and the use of hard-facing on wearing parts have stabilized performance and reduced maintenance requirements. Polymer requirements are low on the new models for most sludge (ca. 5 mg/kg sludge solids). The dewatering market of the future appears to be falling to belt filters and solid-bowl decanter centrifuges, with belt filters dominating the market for small plants and centrifuges seeing more installation in large plants.

Non-Thermal Conversion

Conversion is defined as a process that converts sludge into a product not perceived as sludge. Composting is considered a conversion process. Heat drying, which converts sludge into something recognized not as sludge but as a fertilizer, is also considered a conversion process.

Composting. Composting of sludge has become very popular in the United States in recent years. Composting of sludge with refuse was popular about 30 years ago, but virtually all of these plants have been abandoned. The product was poor and there was too much of it. Composting practice today generally comprises co-composting sludge with a minimum amount of an agricultural waste such as wood chips or rice hulls. The product has a very desirable appearance and a minimum quantity is produced, which generally does not saturate the local market. Other speakers will address composting in detail so further discussion is not needed.

Heat Drying. Heat drying of waste activated sludge is practiced by Houston and Milwaukee and by a few small cities. Costs of fuel have increased the cost of heat drying. No significant future installations are anticipated.

Thermal Conversion

Thermal processes have been proposed for using sludge in brick manufacture, and for converting it to oil or gaseous fuels. None of these processes have reached a practical stage as yet. Incineration is the only thermal conversion process of any significance.

Co-Combustion with Refuse. About 30 years ago, there were several attempts in the United States to burn refuse and sludge together. Some of these failed primarily because they were poorly engineered. Flash drying (the Raymond System marketed by Combustion Engineers, Inc.) using hot gases from refuse burning to dry the sludge was used in a few plants but these too were abandoned. There have been a few recent attempts to co-combust sludge and refuse in which well-dewatered or dried sludge is incorporated into the refuse charged to a conventional traveling grate refuse incinerator. They may prove successful but no trend appears likely. In Europe, there are many successful co-combustion installations. Part of the reason for the difference between U.S. and European practice may be that in the United States federal funds are available for wastewater-associated plant construction costs but not for refuse disposal construction costs. A municipality must come up with its own funds to get a co-combustion facility built, whereas it uses primarily federal funds for a facility combusting only sludge. This unnatural condition has not provided an equal competitive climate for the two approaches. If no federal funds were available for either option, there very likely would be more co-combustion practiced today in the United States.

Sludge Incineration. Probably 80 percent of the sludge that is incinerated is incinerated in multiple hearth furnaces (Figure 10). About 15 percent is incinerated in fluid bed furnaces (Figure 11). The remainder is disposed of by co-combustion and in small electrically heated incinerators (Figure 12). The multiple hearth furnace continues to be the most frequently used device although concern about unburned organic compounds may shift interest toward the fluidized bed furnace. For both incinerator types there is concern about heavy metal emissions. Lead and cadmium, which are frequently found in substantial quantities in sewage sludge, are volatile metals and appear in disproportionate amounts in the fine fraction of the particles carried off by the gas stream leaving a sludge incinerator. The common practice in the United States has been to use water scrubbing (venturi scrubbers followed by a tray scrubber) to remove these particles from the off-gas stream. These devices are inefficient for collection of fine particles. We may see a shift toward electrostatic precipitators or bag houses if state and federal governments develop rules limiting discharges of heavy metals from sludge incinerators.

Ocean Disposal

Federal law prohibits discharges of sludge by outfall into the oceans surrounding the United States, but barging of sludge to dump sites in the ocean is still permitted. Recent decisions require that sludge be dumped at the edge of the continental shelf. For New York City, the barge trip will now be 170 km instead of 19 km. Economic pressure as well as regulatory pressure is likely to cause a shift in emphasis from ocean disposal to land-based disposal options.

Disposal to the Land

Sludge is disposed to landfills, deposited on dedicated land sites, used to renovate abused soils, and is used as a fertilizer or as a soil amendment. Probably 30 percent of sludge goes to landfill, 25 percent to incineration, 10 percent to ocean disposal, and the remainder is used constructively on land. Discussions of deposition of sludge to or into the land will be presented by other speakers.

REFERENCES

(1) U.S. EPA, "Process Design Manual--Sludge Treatment and Disposal," EPA 625/1-79-001, pub. 1979.

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(3) Kowal, N. E., "Health Effects of Land Application of Sewage Sludge," pub. U.S. EPA, Rept. No. EPA/600/1-85-015, Sept. 1985.

(4) U.S. EPA, "Process Design Manual for Upgrading Existing Treatment Plants," pub. 1974.

TABLE 1

PRIMARY SLUDGE CHARACTERISTICS

Characteristic	Range of values	Typical value	Comments
pH	5 - 8	6	-
Volatile acids, mg/l as acetic acid	200 - 2,000	500	-
Heating value, Btu/lb (kJ/kg)	6,800 - 10,000	-	Depends upon volatile content, and sludge composition, reported values are on a dry weight basis.
		10,285	Sludge 74 percent volatile.
		7,600	Sludge 65 percent volatile.
Specific gravity of individual solid particles	-	1.4	Increases with increased grit, silt, etc.
Bulk specific gravity (wet)	-	1.02	Increases with sludge thickness and with specific gravity of solids.
		1.07	Strong sewage from a system of combined storm and sanitary sewers.
BOD_5/VSS ratio	0.5 - 1.1	-	-
COD/VSS ratio	1.2 - 1.6	-	-
Organic N/VSS ratio	0.05 - 0.06	-	-
Volatile content, percent by weight of dry solids	64 - 93	77	Value obtained with no sludge recycle, good degritting; 42 samples, standard deviation 5.
	60 - 80	65	
	-	40	Low value caused by severe storm inflow.
	-	40	Low value caused by industrial waste.
Cellulose, percent by weight of dry solids	8 - 15	10	-
	-	3.8	-
Hemicellulose, percent by weight of dry solids	-	3.2	-
Lignin, percent by weight of dry solids	-	5.8	-
Grease and fat, percent by weight of dry solids	6 - 30	-	Ether soluble
	7 - 35	-	Ether extract
Protein, percent by weight of dry solids	20 - 30	25	-
	22 - 28	-	
Nitrogen, percent by weight of dry solids	1.5 - 4	2.5	Expressed as N
Phosphorus, percent by weight of dry solids	0.8 - 2.8	1.6	Expressed as P_2O_5. Divide values as P_2O_5 by 2.29 to obtain values as P.
Potash, percent by weight of	0 - 1	0.4	Expressed as K_2O. Divide values as K_2O by 1.20 to obtain values as K.

1 Btu/lb = 2.32 kJ/kg

Source: Table 4-2, p. 4-8, Reference 1.

TABLE 2

ACTIVATED SLUDGE CHARACTERISTICS

Characteristic	Range of values	Typical value	Comments
pH	6.5 - 8	-	Can be less in high purity oxygen systems or if anaerobic decomposition begins.
		5.5	Baltimore, Maryland
Heating value, Btu/lb (kJ/kg)	-	6,540 (15,200)	Increases with percent volatile content
Specific gravity of individual solid particles	-	1.08	
Bulk specific gravity	-	$1.0 + 7 \times 10^{-8} \times C$	C is suspended solids concentration, in mg/l.
Color	-	Brown	Some grayish sludge has been noted. Activated sludge becomes black upon anaerobic decomposition.
COD/VSS ratio	-	2.17	
Carbon/nitrogen ratio	-	12.9	Baltimore, Maryland
	-	6.6	Jasper, Indiana
	-	14.6	Richmond, Indiana
	-	5.7	Southwest plant, Chicago, Illinois
	-	3.5	Milwaukee, Wisconsin (heat dried)
Organic carbon, percent by weight of dry solids	17 - 41	-	Zurich, Switzerland
	23 - 44	-	Four plants
Nitrogen, percent by weight of dry solids (expressed as N)	4.7 - 6.7	-	Zurich, Switzerland
	-	5.6	Chicago, Illinois
	2.4 - 5.0	-	Four plants
	-	6.0	Milwaukee, Wisconsin
Phosphorus, percent by weight of dry solids as P_2O_5 (divide by 2.29 to obtain phosphorus as P)	3.0 - 3.7	-	Zurich, Switzerland
	-	7.0	Chicago, Illinois
	2.8 - 11	-	Four plants
	-	4.0	Milwaukee, Wisconsin
Potassium, percent by weight of dry solids as K_2O (divide by 1.20 to obtain potassium as K)	0.5 - 0.7	-	Zurich, Switzerland
	-	0.56	Chicago, Illinois
	-	0.41	Milwaukee, Wisconsin
Volatile solids, percent by weight of dry solids (percent ash is 100 minus percent volatile)	61 - 75	-	Zurich, Switzerland
	-	63	
	62 - 75	-	Four plants
	59 - 70	-	Renton, Washington (Seattle Metro), 1976 average
	-	76	
		88	San Ramon, California (Valley Community Services District), 1975 average
Volatile solids (continued)	-	81	Central plant, Sacramento County, California, July 1977 - June 1978 average
Grease and fat, percent by weight of dry solids	5 - 12	-	Ether extract
Cellulose, percent by weight of dry solids		7	Includes lignin
Protein, percent by weight of dry solids	32 - 41	-	-

Source: Table 4-6, p. 4-28, Reference 1.

TABLE 3

PERCENTILE DISTRIBUTION OF METALS
IN DIGESTED SLUDGE

(ALL FIGURES MG/KG DRY SLUDGE BASIS)

METAL	PERCENTILE GROUPING PERCENT EQUAL TO OR LESS THAN STATED VALUE					NO. OF TREATMENT PLANTS
	25%	50%	75%	90%	95%	
SILVER	<100	100	230	430	450	23
BORON	300	350	450	490	870	13
CADMIUM	15	31	67	80	140	18
CALCIUM	22,800	30,000	45,200	49,000	58,800	23
CHROMIUM	395	1,100	2,700	4,000	5,820	23
COBALT	<100	<100	260	500	520	23
COPPER	900	1,230	2,120	2,970	4,310	24
MERCURY	5.1	6.6	8.5	11	12	22
MANGANESE	160	380	770	4,860	6,080	24
NICKEL	300	410	550	1,170	1,720	24
LEAD	<500	830	2,000	2,770	4,370	24
STRONTIUM	100	175	340	1,490	1,790	22
ZINC	1,640	2,780	5,000	9,880	11,100	24

Source: Reference 2.

Table 4. **Most Frequently Detected Priority Organics in Raw Municipal Sludge (Burns and Roe 1982)**

Compound	Detection Frequency (%)	Concentration Range (µg/l)
Bis(2-ethylhexyl)phthalate	95	2- 47,000
Toluene	94	1- 427,300
Dichloromethane	73	1- 10,500
Ethylbenzene	63	1- 4,200
Benzene	61	1- 953
1,2-Trans-dichloroethylene	60	1- 96,000
Trichloroethylene	54	1- 32,700
Pyrene	53	1- 1,700
Phenanthrene	53	1- 10,100
Phenol	50	5- 17,000
Anthracene	48	1- 10,100
Di-n-butylphthalate	45	1- 6,900
Fluoranthene	44	1- 9,930
Butylbenzylphthalate	43	2- 45,000
Tetrachloroethylene	40	1- 2,800
1,1-Dichloroethane	34	1- 2,885
Naphthalene	34	1- 5,200
Chrysene	31	1- 1,500
1,2-Benzanthracene	27	1- 1,500
Trichloromethane (Chloroform)	24	1- 366
1,1,1-Trichloroethane	19	1- 10,910
1,4-Dichlorobenzene	17	2- 12,000
1,2-Dichlorobenzene	16	3- 1,319
1,1,2,2-Tetrachloroethane	15	1- 3,040
Pentachlorophenol	14	10- 10,500
Chlorobenzene	13	1- 687
1,2,4-Trichlorobenzene	13	2- 8,300
3,4-Benzofluoranthene	11	1- 2,400
Di-n-octylphthalate	10	4- 1,024
1,2-Dichloroethane	10	1- 10,010

Source: Table 21, p. 42, Reference 3.

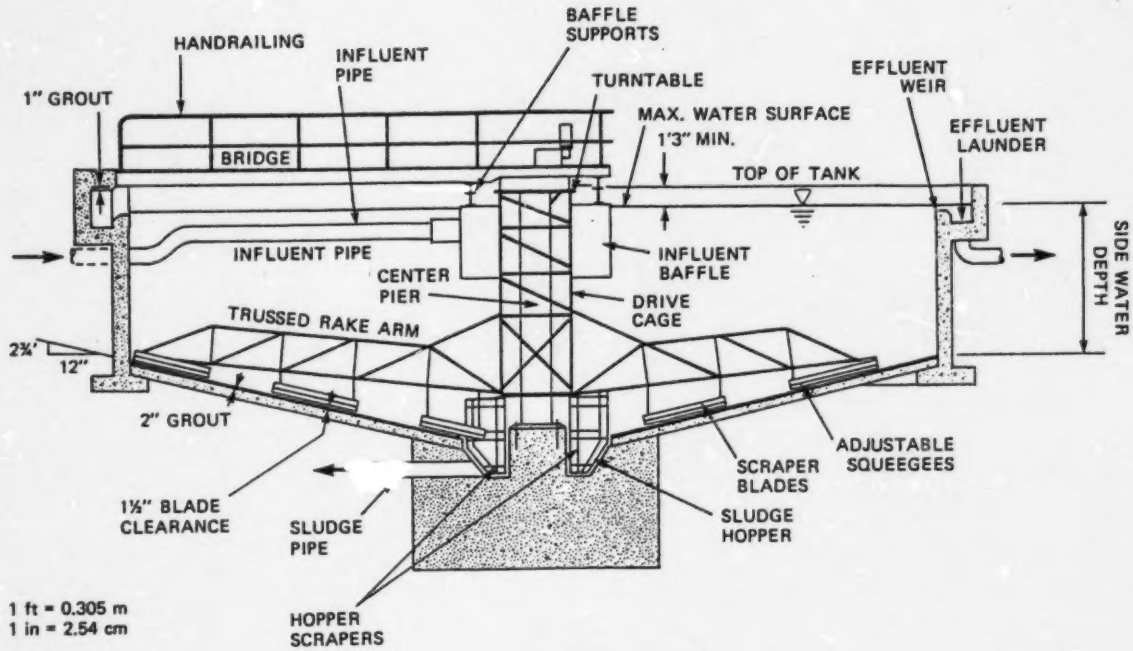


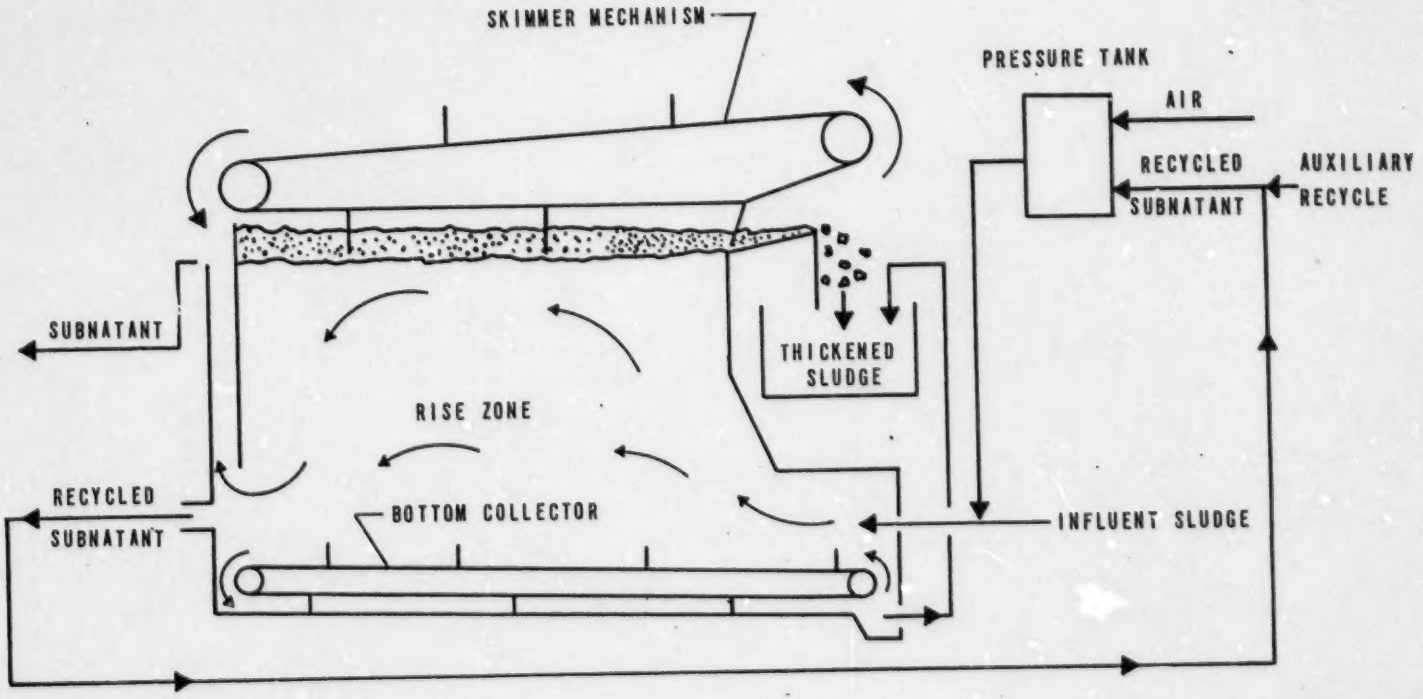
FIGURE 1

CROSS SECTIONAL VIEW OF A TYPICAL CIRCULAR GRAVITY THICKENER

Source: Figure 5-3, p. 5-6, Reference 1.

FIGURE 2

SCHEMATIC OF AN AIR FLOTATION UNIT



Source: Figure 10-5, p. 10-15, Reference 4.

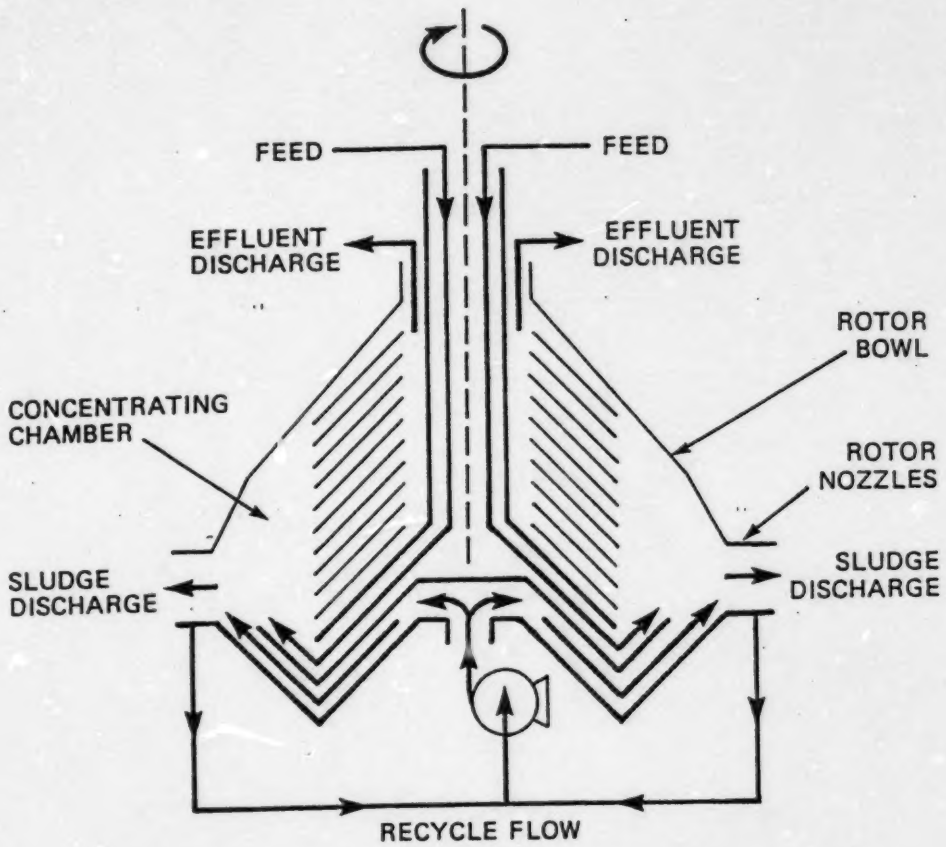


FIGURE 3

SCHEMATIC OF A DISC NOZZLE CENTRIFUGE

Source: Figure 5-17, p. 5-41, Reference 1.

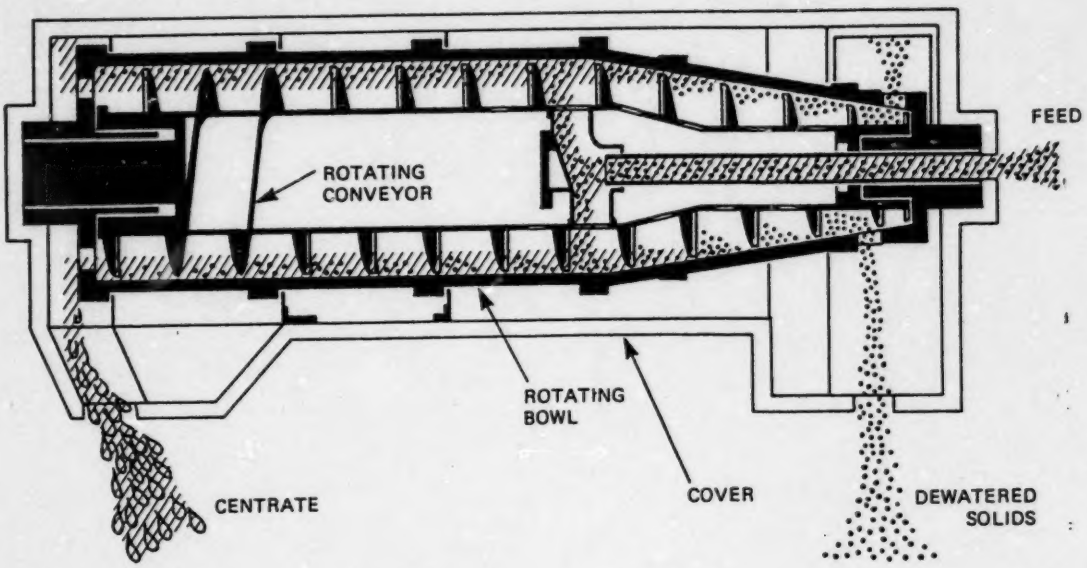


FIGURE 4

SCHEMATIC OF TYPICAL SOLID BOWL DECANTER CENTRIFUGE

Source: Figure 5-22, p. 5-50, Reference 1.

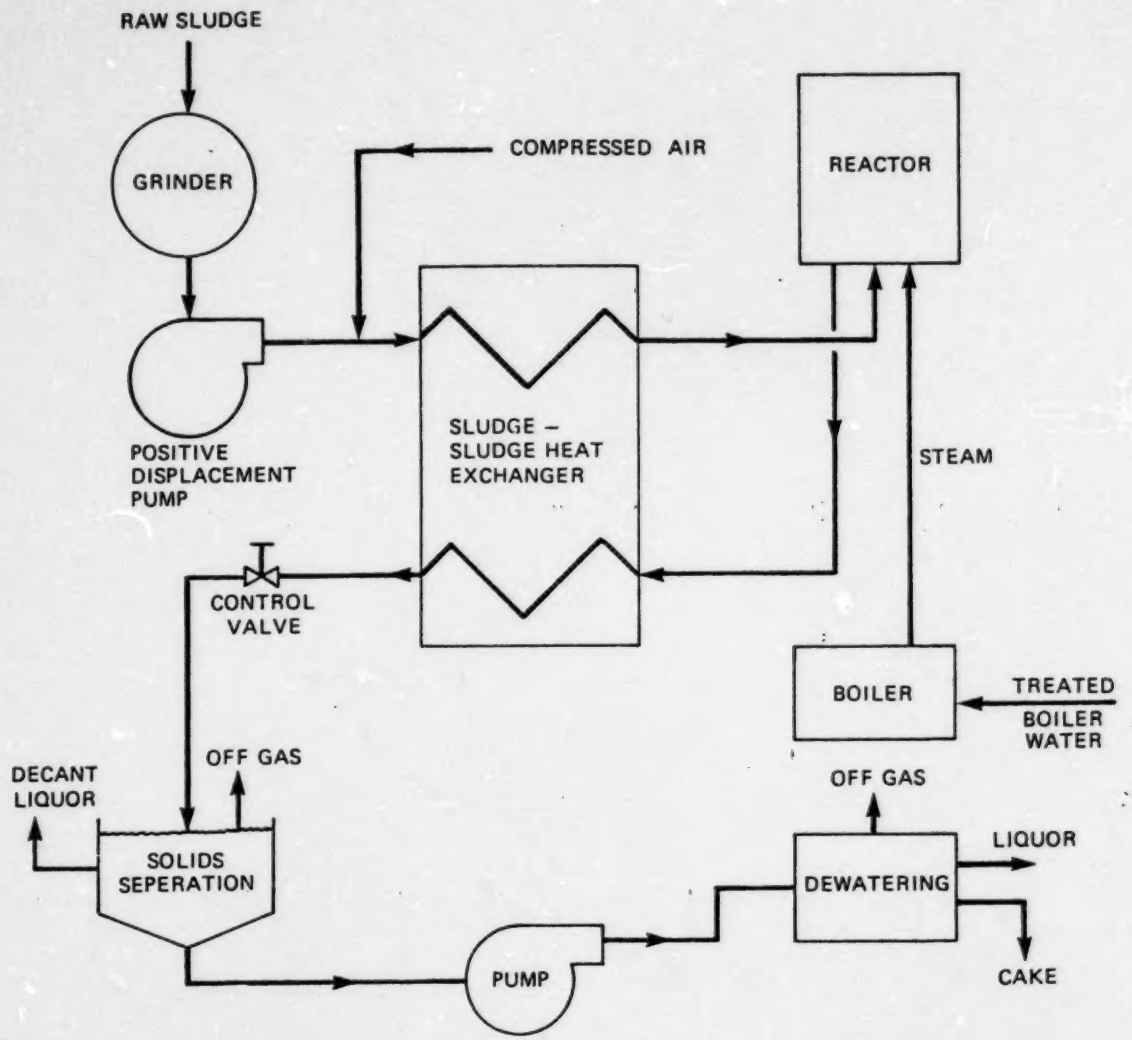
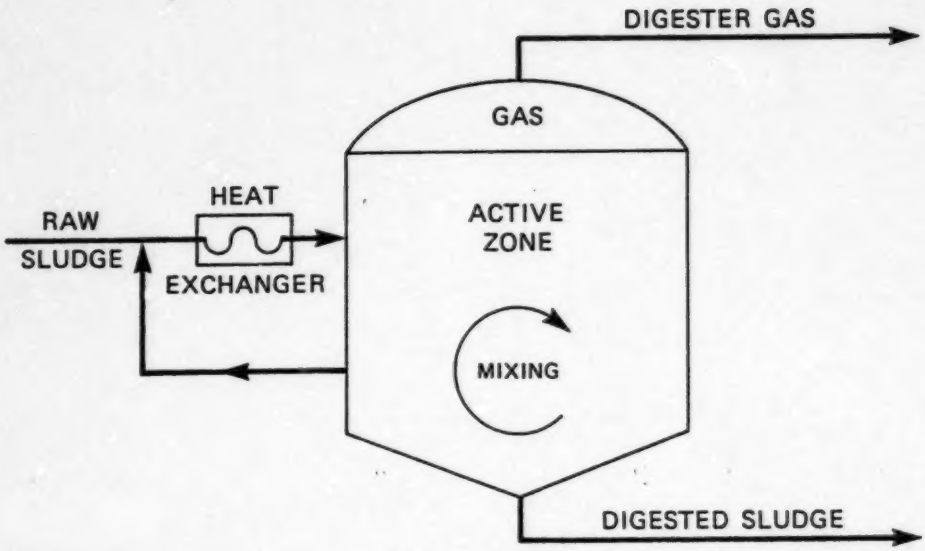


FIGURE 5

GENERAL THERMAL SLUDGE CONDITIONING FLOW SCHEME FOR AN OXIDATIVE SYSTEM

Source: Figure 8-18, p. 8-33, Reference 1.



HEATED TO CONSTANT TEMPERATURE
MIXED
CONTINUOUS FEEDING AND WITHDRAWAL
DETENTION TIME: 10-15 DAY MINIMUM
LOADING RATE: 0.10-0.50 lb VSS/cu ft/day
(1.6-8.0 kg VSS/m^3/day)

FIGURE 6

SINGLE-STAGE, HIGH-RATE ANAEROBIC DIGESTION SYSTEM

Source: Figure 6-3, p. 6-9, Reference 1.

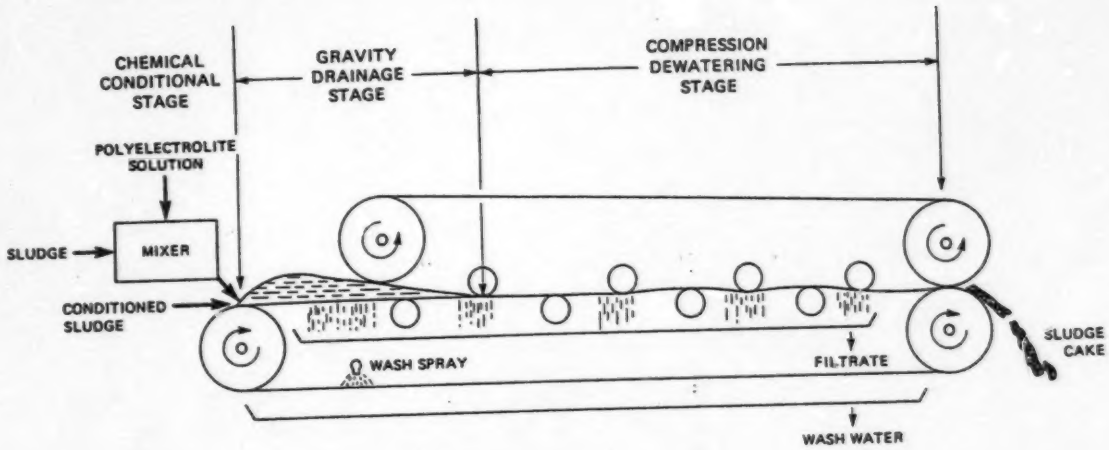


FIGURE 7

THE THREE BASIC STAGES OF A BELT PRESS

Source: Figure 9-22, p. 9-46, Reference 1.

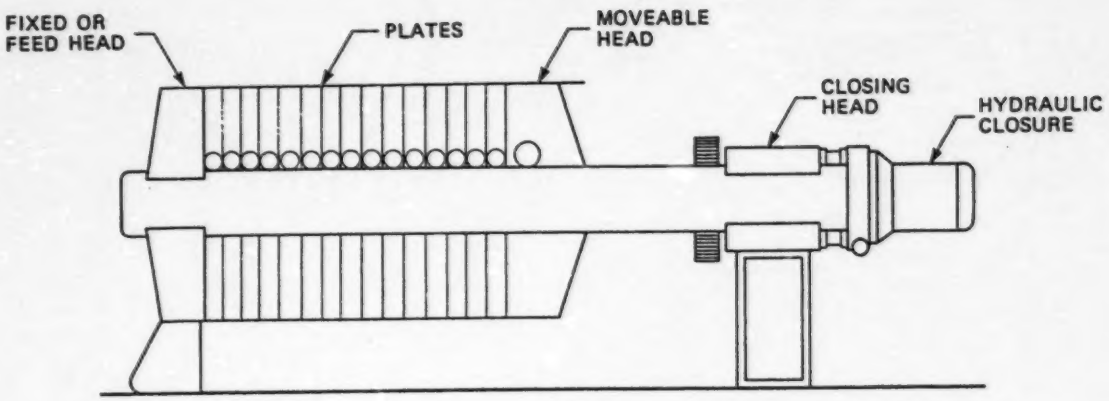


FIGURE 8a

SCHEMATIC SIDE VIEW OF A RECESSED PLATE PRESSURE FILTER

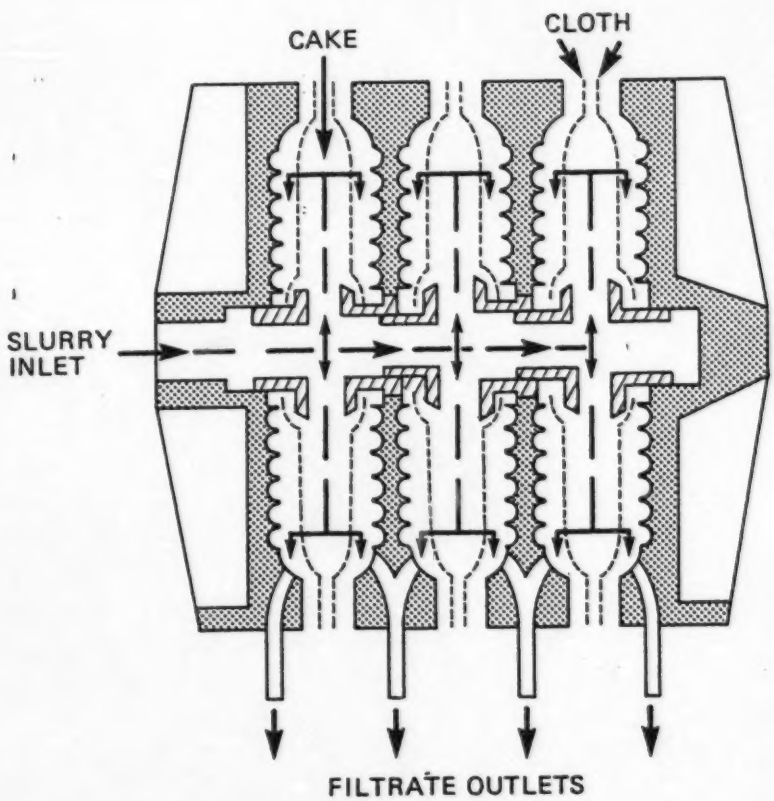


FIGURE 8b

CROSS SECTION OF A FIXED-VOLUME RECESSED PLATE FILTER ASSEMBLY

Source: Figure 9-25, 9-26, p. 9-53, Reference 1.

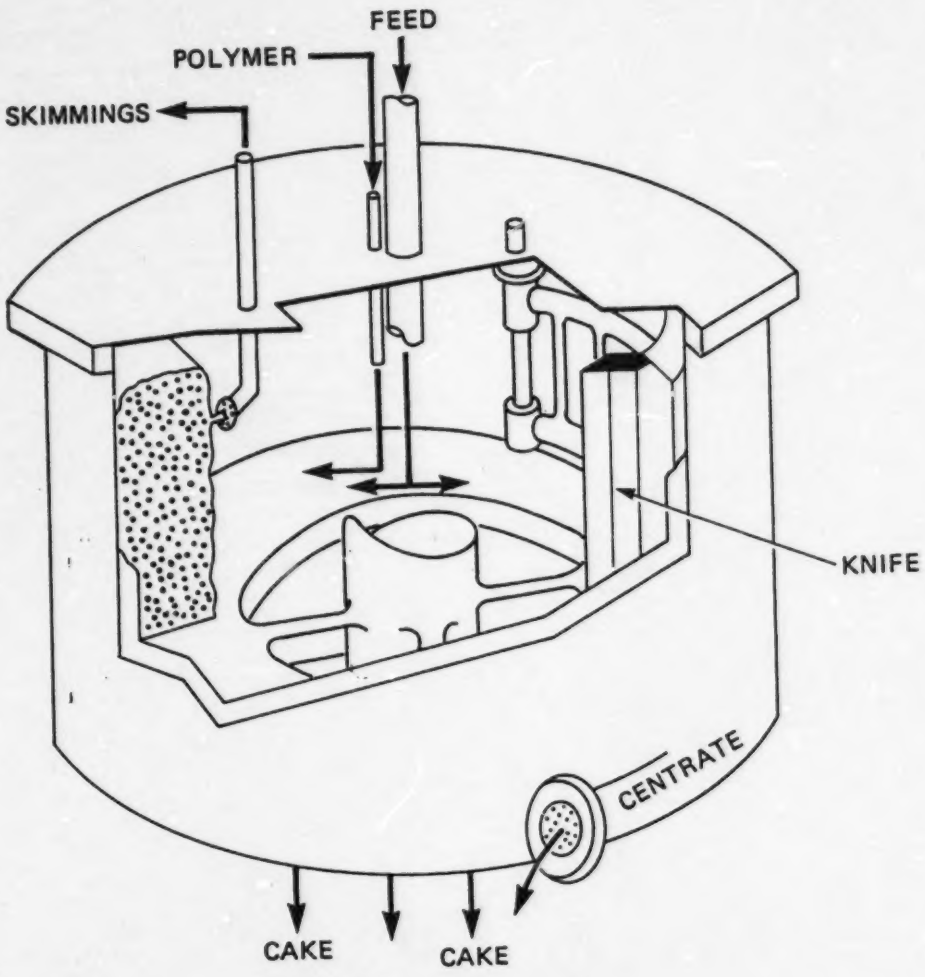


FIGURE 9

GENERAL SCHEMATIC OF IMPERFORATE BASKET CENTRIFUGE

Source: Figure 5-20, p. 5-46, Reference 1.

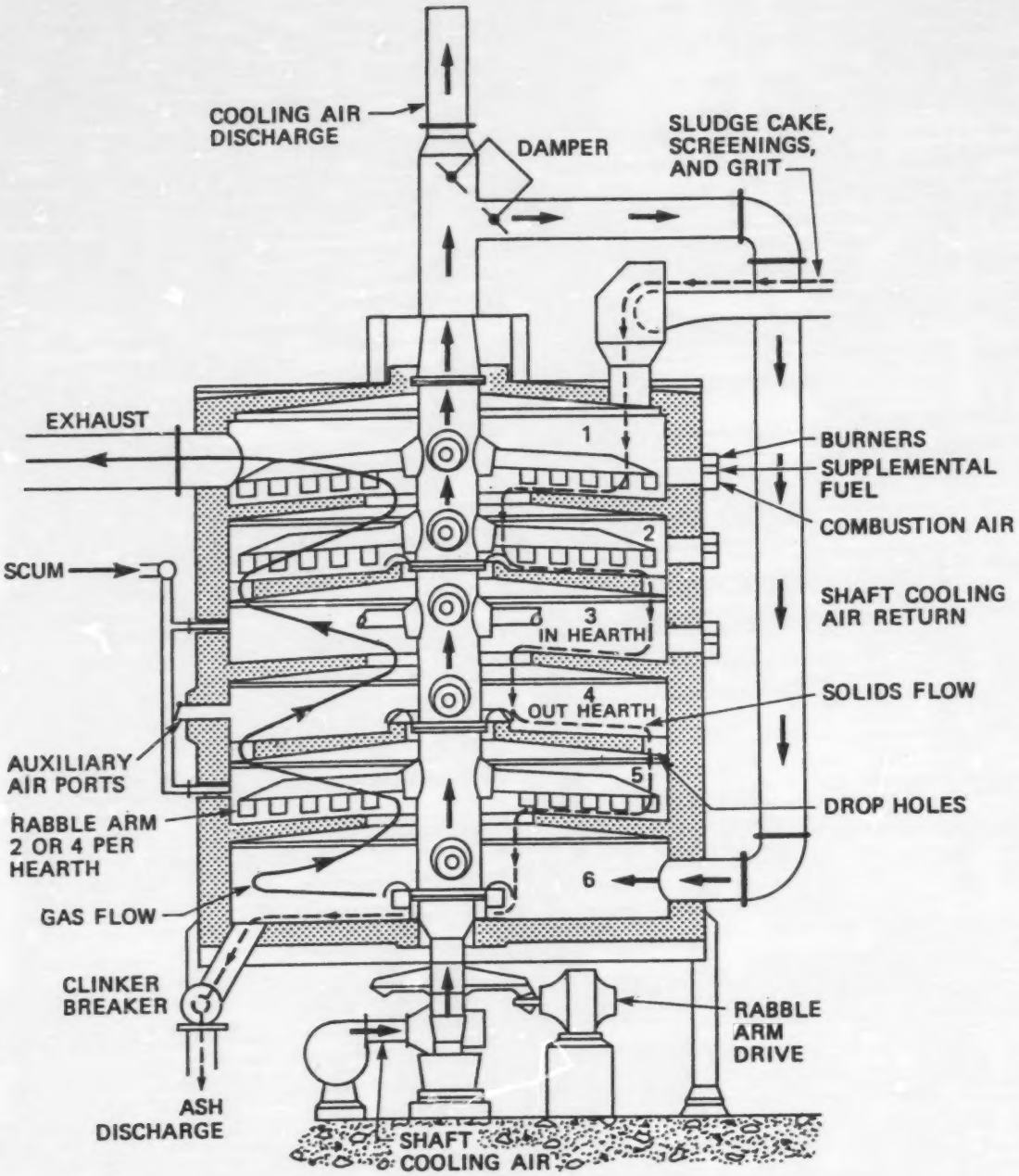


FIGURE 10

CROSS SECTION OF A MULTIPLE-HEARTH FURNACE

Source: Figure 11-6, p. 11-33, Reference 1.

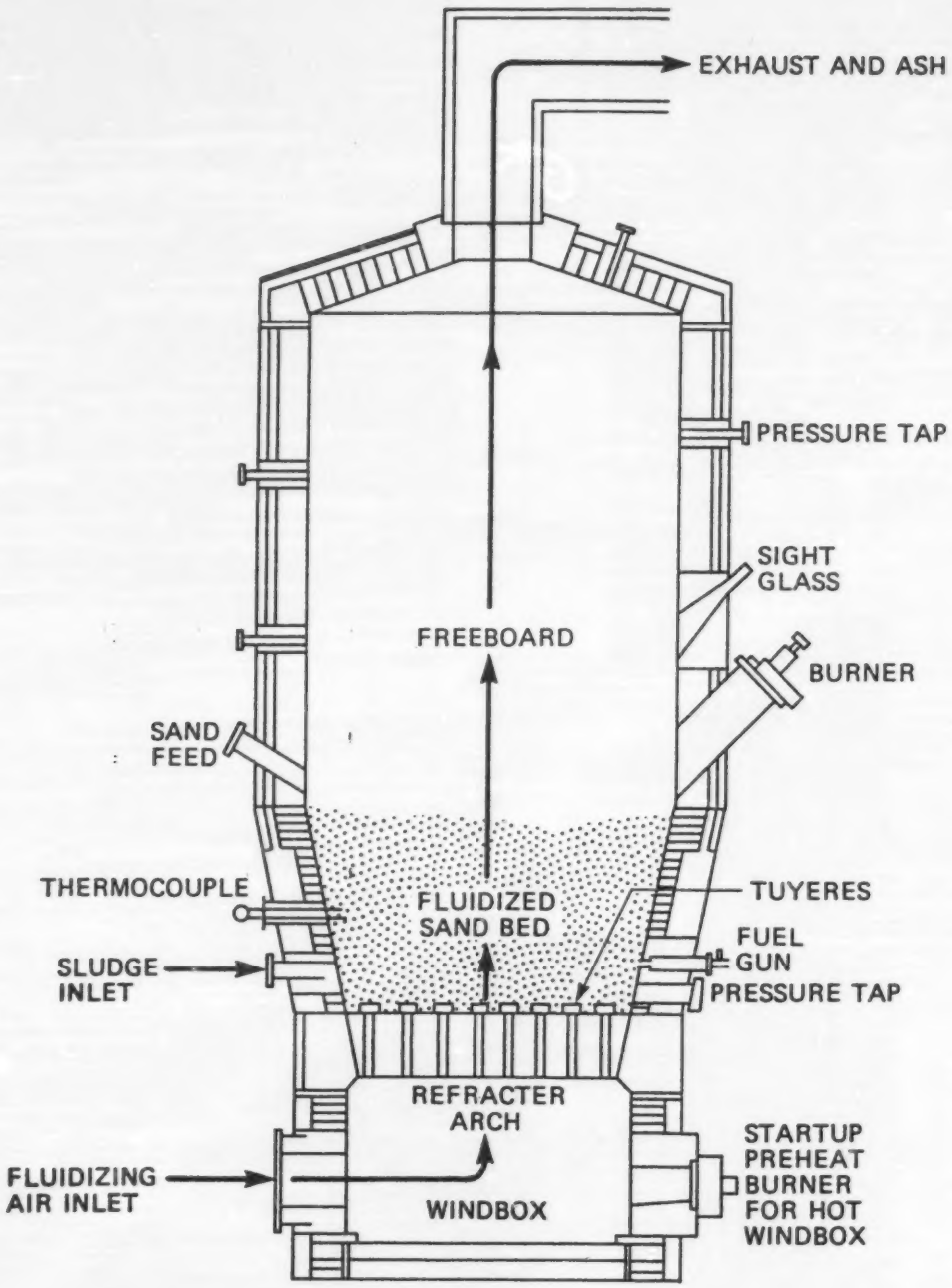


FIGURE 11

CROSS SECTION OF A FLUID BED FURNACE

Source: Figure 11-17, p. 11-50, Reference 1.

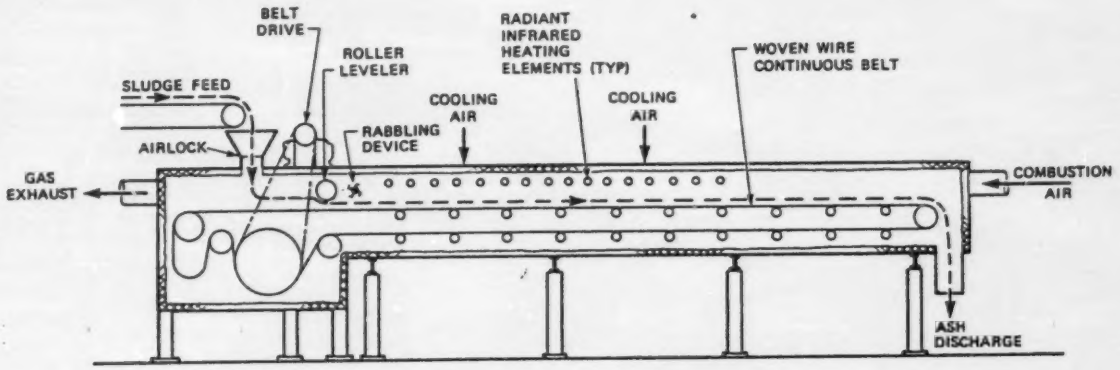


FIGURE 12

CROSS SECTION OF AN ELECTRIC INFRARED FURNACE

Source: Figure 11-21, p. 11-55, Reference 1.